3.4 PREFILTERS FOR HEPA FILTERS

3.4.1 FILTER DESCRIPTIONS

The service life of HEPA filters can often be extended by using less efficient filters that selectively remove the largest particles and fibers from the incoming air stream. In some cases, HEPA filter lifetimes can be increased by as much as four times with multiple prefilter changes during the interval between HEPA changes. A sound rule of thumb is that HEPA filters should be protected from (1) particles larger than 2 µm in diameter, (2) lint, and (3) particle concentrations greater than 2.3 mg/m^3. Selection of an appropriate prefilter includes consideration of (1) the rapidity of filter resistance buildup and associated energy costs, (2) the size and complexity of the resulting filtration system, and (3) the fact that replacement filters and associated costs generally increase with increasing prefilter efficiency. It has been estimated that, with frequent prefilter replacements, savings in filter system operation could be as much as one-third the cost of operating without prefilters. Assessment of an acceptable combination of prefilters and HEPA filters depends on the dust-loading and efficiency characteristics of the different filter types available for the particular aerosol to be filtered. The clogging susceptibility of HEPA filters will vary with the dust and filtration characteristics of the prefilters.

The types of filters used as prefilters are also widely used for cleaning ventilation supply air in conventional HVAC systems. The important advantage of filtering ventilation supply air for many operations that generate radioactive particles is a reduction in the dust load that reaches the final contaminated filters. This helps extend the service life of the exhaust filters, thereby reducing overall system costs because the supply air filters can be changed without resorting to radiation protection measures--often the most costly aspect of a contaminated exhaust filter change. These filters have a wide range of efficiencies, including 5 to 10 percent for warm air residential heating systems; 35 to 45 percent for ventilation of schools, stores, and restaurants; and 85 to 95 percent for fully air-conditioned modern hotels, hospitals, and office towers.

3.4.2 CLASSES, SIZES, AND PERFORMANCE CHARACTERISTICS OF PREFILTERS

The most widely used test methods for ventilation air filters are published by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) as Standard 52.1-92,[30] which contains two different protocols. One uses a prepared test dust consisting of road dust, carbon black, and cotton fibers. In this procedure, the test dust is aerosolized by compressed air and blown into the filter at a concentration many times that normally found in ambient air. The filter is rated by the weight percent of dust retained. This obsolete test method hearkens back to the days when coal was the only fuel and has little relevance to today's air filter requirements. The second test method uses unaltered atmospheric air as the test medium and rates filter efficiency on the basis of the percent reduction in discoloration of simultaneous samples taken on white filter papers upstream and downstream of the filter being tested. Reductions in discoloration cannot be related to weight percent efficiency. In addition to dust-collecting efficiency, the first test procedure measures filter resistance increase with dust deposition and dust-holding capacity. Ventilation filters in the 35 to 95 percent efficiency range are evaluated by the atmospheric dust discoloration test.

TABLE 3.7 shows the ASHRAE ventilation filter classes. For comparison purposes, the HEPA filter is rated at 100 percent for both the stain-efficiency and artificial dust arrestance tests. Because the atmospheric dust test is based on the staining capacity of the dust that penetrates the filter, compared to the staining capacity of the entering dust, it is not a true measure of particle-removal efficiency for any one particle-size range. **TABLE 3.8** shows a more representative comparison of performance.

It should be pointed out that ASHRAE Standard 52.1-92[30] tests have replaced those sanctioned formerly by the Air Filter Institute and the Dill Dust-Spot Test of the National Bureau of Standards (now the National Institute for Technology and Standards). Care must be taken in the interpretation of data from the ASHRAE tests. Arrestance test results highly depend on particles that exceed 1 μm in diameter, but the ambient atmospheric dust test results depend on the nature and concentration of aerosol particles at the testing location. As a rule of thumb, the average particle size of the urban aerosol is assumed to be 0.5 μm. The results of the various tests are not comparable, and a filter determined to be efficient by one test may be determined to be inefficient by another. Users should examine the test used to evaluate a filter's efficiency to properly understand the results. Efficiency tests are made on prototype filters, and the results are extrapolated to other units of similar design (certification of every prefilter by testing would be too costly).

TABLE 3.9 lists the comparative performance of the different groups of filters. Values stated for dust-holding capacity were determined with resuspended synthetic dust mixtures. Dust-holding capacity varies with the nature and composition of the particles (e.g., carbon black, cotton linters). Dust-holding capacity under service conditions cannot be predicted accurately on the basis of manufacturers' data. Air resistance is the primary factor in prefilter replacement. Although manufacturers recommend specific values of resistance for prefilter replacement, loss of adequate airflow is often a more reliable indicator of system performance and is also more cost-effective. Panel filters will plug rapidly under heavy loads of lint and dust. An accumulation of surface lint may increase the efficiency of an extended-medium filter by adding "cake" filtration principles to the existing physical mechanisms. The extended-medium prefilter will plug readily in an airstream carrying profuse smoke and soot from a fire. Operation at airflows below rated capacity will extend the service lives of filters and be more cost-effective by reducing the frequency of filter replacement. On the other hand, when airflow exceeds rated values, dust-loading rate and system costs begin to increase exponentially along with proportional increases in airflow. [ASHRAE also publishes Standard 52.2-99,[36] which gives methods for testing filter efficiency by particle size using optical particle counters, including lasers.]

Table 3.7 – Classification of common air filters

Group	Efficiency	Filter Type	Stain test efficiency (%)	Arrestance (%)
I	Low	Viscous impingement, panel type	<20[a]	40-80[a]
II	Moderate	Extended medium, dry type	20-60[a]	80-96[a]
III	High	Extended medium, dry type	60-98[b]	96-99[a]
HEPA	Extreme	Extended medium, dry type	100[c]	100[a]

[a]Test using synthetic dust.
[b]Stain test using atmospheric dust.
[c]ASHRAE 52.1-92.[30]

Table 3.8 – Comparison of air filters by percent removal efficiency for various particle sizes

Group	Efficiency	Removal efficiency (%) for particle size –			
		0.3 μm	1.0 μm	5.0 μm	10.0 μm
I	Low	0-2	10-30	40-70	90-98
II	Moderate	10-40	40-70	85-95	98-99
III	High	45-85	75-99	99-99.9	99.9
HEPA	Extreme	99.97 min	99.99	100	100

Table 3.9 – Airflow capacity, resistance, and dust-holding capacity of air filters

Group	Efficiency	Airflow capacity (cfm per square foot of frontal area)	Resistance (in.wg)		Dust-holding capacity (g/1000 cfm of airflow capacity)
			Clean filter	Used filter	
I	Low	300-500	0.05-0.1	0.3-0.5	50-1000
II	Moderate	250-750	0.1-0.5	0.5-1.0	100-500
II	High	250-750	0.20-0.5	0.6-1.4	50-200

3.4.3 Construction of Prefilters

Group I panel filters (viscous impingement filters) are shallow, tray-like assemblies of coarse fibers (glass, wool, vegetable, or plastic) or metal mesh enclosed in a steel or cardboard casing. The medium is usually coated with an inhibited viscous oil or adhesive to improve trapping and retention of particles. Single-use disposable and cleanable-reusable types are available. The latter have metal mesh and generally are not used in nuclear applications for effluent or process air cleaning because of the high labor costs associated with cleaning and disposal of entrapped radioactive materials. A disposable panel filter has a fairly high dust-holding capacity, low airflow resistance, low initial and operating costs, and high removal efficiency for large particles. It is particularly effective against fibrous dust and heavy concentrations of visible particles, but is ineffective for smaller particles. For nuclear service, it is less cost-effective than the more costly Group II or III filters that provide better protection for the HEPA filter.

Group II (moderate-efficiency) and Group III (high-efficiency) filters are usually comprised of extended-medium, dry-type, single-use disposable units. The filter medium is pleated or formed into bags or socks to provide a large filter surface area with minimal face area. They are not coated with adhesive. The particle size efficiency of Group II filters is moderate to poor for submicrometer-sized particles, but often approaches 100 percent for particles greater than 5 μm. In most cases, the pressure drop of extended-media Group II filters varies directly with efficiency. Group II filters are recommended for high lint- and fiber-loading applications. The large filter area relative to face area permits duct velocities equal to or higher than those of panel filters.

Group III filters are preferred when higher efficiency for smaller particles is desired. The dust-holding capacity of Group III filters usually is lower than that of Group II filters.

Electrostatic and Electrified Filters

An electrostatic charge may be induced on filter fibers by triboelectrification and by sandwiching the fiber bed between a high voltage and a grounded electrode. Triboelectrification can be used to induce a high electrostatic charge on suitable high dielectric materials, but under practical-use conditions, the charge is subject to rapid dissipation due to air humidity, oily particles, fiber-binding particles, and other interference. Continuously activated electrodes can induce a more permanent charge.

A program to develop electrofibrous filters, undertaken by DOE at the Lawrence Livermore National Laboratory, has proved them effective in providing greater efficiency and longer service life for the prefilters used to protect HEPA filters. They have been used in glove boxes and for other applications. Laboratory tests using test and sodium chloride aerosols have shown that an "electrofibrous prefilter increases in efficiency from 40 to 90 percent as 10 kV is applied to the electrode." A comparison of uncharged, triboelectrically charged, and permanently charged fibrous filters demonstrated the higher collection efficiency of the permanently charged filter design for submicrometer particles. When continuously charged electrofibrous filters were applied as prefilters for HEPA filters in exhaust air systems or glove boxes used to burn uranium turnings, they significantly prolonged the life of the final filters.

3.4.4 OPERATION AND MAINTENANCE OF PREFILTERS

All materials of construction for prefilters must be compatible with those of the downstream HEPA filters they are designed to protect. Therefore, they must conform to the rigorous physical properties prescribed for HEPA filters, e.g., resistance to shock, vibration, tornado, earthquake, moisture, corrosion, and fire. Survivability under the specific operational conditions and requirements must be addressed when prefilters are selected because moisture or corrosive products in the airstream may limit the choice of filter. Although many filter media will not withstand acid or caustic attack, glass fibers are corrosion-resistant except for fluorides. However, the casing and face screen materials may be less so. Aluminum may deteriorate in marine air, from caustics, or from carbon dioxide. Plastics have poor heat and hot air resistance and generally will not satisfy UL requirements. Condensation from high humidity and sensible water may plug a prefilter and result in more frequent replacement. In general, a prefilter made of construction materials identical to those in the HEPA filter will have equivalent corrosion and moisture resistance. Any increase in resistance from moisture accumulation will be greater for ASHRAE Class III filters than for Class I or II filters. UL classifies ventilation air filters in two categories with respect to fire resistance.[31] When clean, UL Class I filters do not contribute fuel when attacked by flame and emit a negligible quantity of smoke. UL Class II filters are permitted to contain some small amount of combustible material, but they must not contribute significantly to a fire. The collected material on in-service UL-approved Class I and II filters may burn vigorously and create a fire that is difficult to extinguish. Therefore, use of a UL-rated prefilter should not lead to an unwarranted sense of security on the part of the user. UL maintains a current listing of filters that the requirements of their standards.[32]

Most types of prefilters are suitable for continuous operation at temperatures not exceeding 65 to 120 degrees Celsius (149 to 248 degrees Fahrenheit). Other types with glass-fiber media in steel or mineral board frames may be used at temperatures as high as 200 degrees Celsius (392 degrees Fahrenheit). Users of high-temperature prefilters should take a conservative view of performance claims, particularly claims related to efficiency at operating temperature.

Because of waste disposal requirements, the preferred choice of a prefilter for nuclear applications is the single throwaway cartridge. A replaceable-medium filter offers an advantage over the throwaway because the bulk of material that needs to be discarded is smaller and handling and disposal costs are minimized. However, re-entrainment of contaminants and contamination of the peripheral area are possible because the medium is removed from the system and prepared for disposal. The replaceable-medium type is not recommended for toxic exhaust systems. The cleanable-medium filter is undesirable for nuclear systems because of the extensive downtime of the system that is required for changing and decontaminating areas in proximity to the filter installation.

3.5 DEEP-BED FILTERS

Deep-bed filters were designed, built, and placed in service early in the development of nuclear technology for treating off-gasses from chemical processing operations. The first, a sand filter, was constructed at the Hanford, Washington nuclear facility in 1948, and deep-bed glass fiber filters were constructed soon after. These were not considered competitive with then-current versions of the HEPA filter (the CWS-Type 6 or AEC-Type 1), but were thought to have a different function. With the thin-bed filters, the intent is usually to replace or clean the filter medium periodically. The deep-bed filter, on the other hand, usually has as its objective the installation of a unit which will have a long life, in the dust capacity sense, of say five to twenty years, corresponding to either the life of the process or the mechanical life of the system. Thus, when the resistance starts increasing rapidly, the entire filter installation will be abandoned and replaced with a new unit rather than replacing or cleaning the filter medium. In fact, the life span of some of the deep-bed filters constructed during the early 1950s has not yet been entirely expended. A partial explanation for this longevity is the original design concept that deep-bed filters will be used where the total aerosol concentration is usually on